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Decaying Organic Materials and Soil Quality in the Inland Northwest: A Management Opportunity

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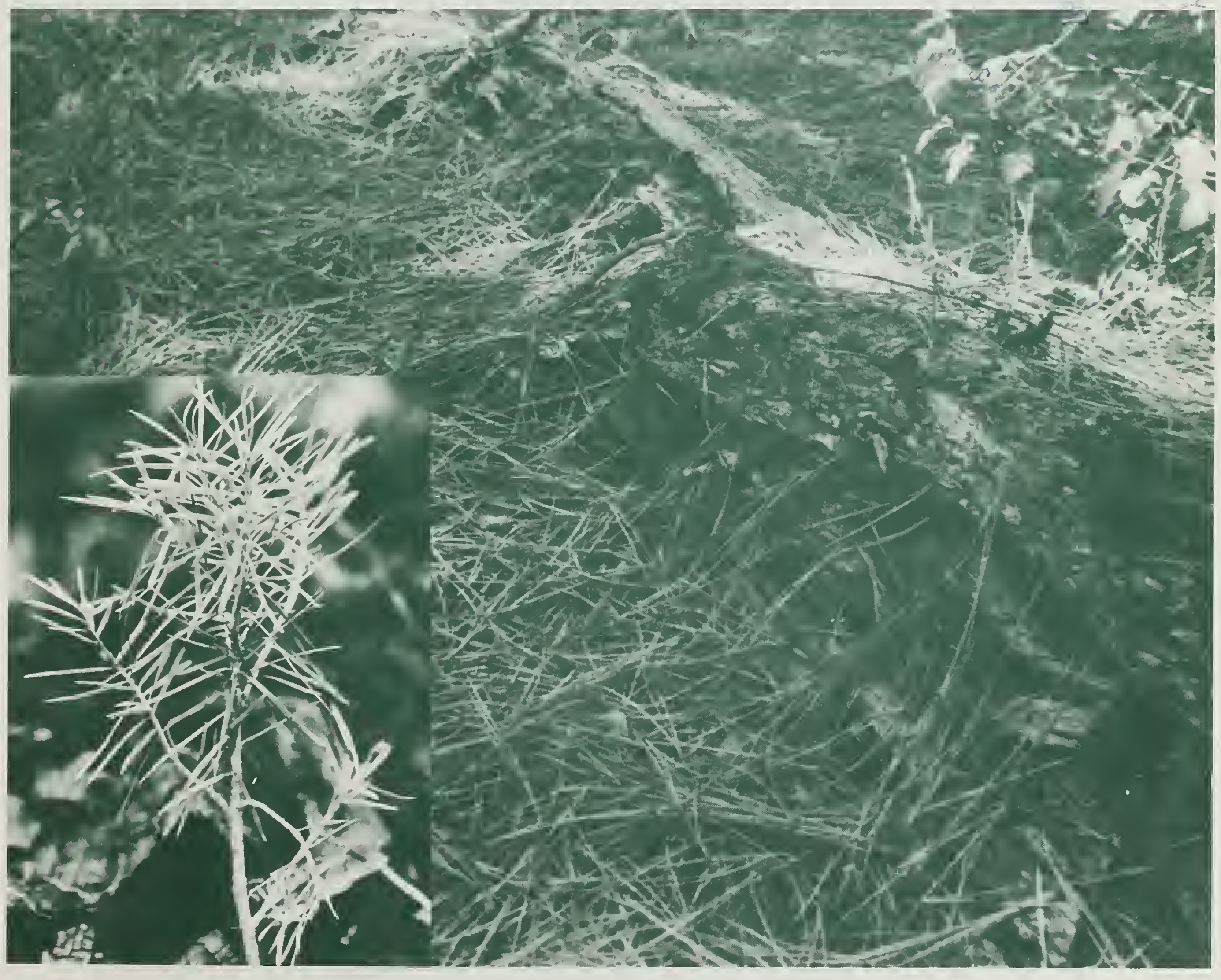

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RESEARCH SUMMARY

Organic debris, including wood residues, provides parent materials for development and function of organic mantles on forest soils. Along with providing a storehouse of nutrients and moisture, organic materials provide either the environment or the energy source for microorganisms critical to both the nutritional quality of forest soils and the ability of conifers to extract nutrients and moisture from the soil. The role and relative importance of specific organic components can vary substantially with site and conifer species. Age of the trees appears to have less of an effect on importance of organic matter than site or species. Of the many organic materials incorporated in a forest soil, the woody component is in many ways the most important. To protect productive potential of forest soils, a continuous supply of organic materials must be provided, particularly in harsh environments. In case of excess losses of the organic mantle, complete recovery of the site may require several hundred years, even with proper management.

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324 25th Street
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INTRODUCTION

As practicing biologists, forest managers intuitively recognize that the organic forest floor, including decaying tree boles, has specific functions in forest ecosystems. Nearly all management operations have the potential to alter soil organic depositions and underlying mineral horizons. Some operations can cause considerable disruption to surface soil horizons. Site preparation procedures prior to reforestation frequently cause considerable physical soil disturbance. There is potential for increased use of prescribed burning as a site preparation and fuel management system. Application of intensive utilization practices and their greater wood removal in some areas of the Inland West appears probable. Appropriate application of these techniques can minimize soil disturbance. Inappropriate actions will likely reduce site productivity.

Many forests in the Inland Northwest have been accumulating high fuel loadings since the advent of Euro-American settlement. The danger of catastrophic wildfires that destroy forest floor organic materials (OM) is increasing in these areas. Extensive stands of overcrowded and stagnated timber are common throughout the Inland West. Many of these stands are probably growing in fire-damaged soils.

We have been investigating the potential for fire and logging to alter the possible roles that various organic materials, including woody residues, have in forested ecosystems. Our studies show that quantities of OM and their distribution, especially decaying wood and humus, have integral and sometimes critical roles to play in supporting the growth of forest trees. This report is a summary of this research and our assessment of how current forest practices are likely to impact future forest productivity in the Inland Northwest. We discuss a wide range of forest cover types, from warm, dry ponderosa pine (*Pinus ponderosa* Laws.) to cool, moist subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.).

For development and presentation of our results, concepts, and recommendations, we have emphasized measurements, or estimates based on measurements, taken from forest stands representative of commercial forests in the Inland Northwest. Literature citations are used only to support specific points required to develop the concepts presented. Because of space limitations and difficulty of extrapolating from nonregional data, where possible we have emphasized literature based on research originating in the Inland Northwest.

Characteristics typifying the region discussed are a climate transitional between northern Pacific and continental United States with wet, cloudy winters and dry, sunny summers. Soils have moderate to low productivity potential (Pfister and others 1977), tend to be nitrogen limited, and usually have shallow organic mantles (Clayton and Kennedy 1985; Jurgensen and others 1979).

SOIL MICROBIAL FRAMEWORK

The chemical energy bound in soil organic matter and tree residues fuels important microbiological activities. Many microbes function as nutrient and OM (carbon) recycling agents. These microbes release or mineralize nutrients contained in plant remains, create many types of decay products (for example, brown, white, cubical, and stringy rots), capture and retain nutrients that might otherwise be leached from the root zone (Vitousek and others 1982), and form many of the chemical and physical components (for example, soil humus and organic cation exchange sites) responsible for maintenance of structure and fertility of forest soils. The wood decay fungi are perhaps the most important of these microbes because of the additional role rotted wood plays in sustaining certain conifer rooting, nitrogen (N) input, and nutrient storage capabilities.

Decay fungi have three major roles in the forest soil development process: (1) to break down plant residues and recycle the carbon (fig. 1A to C); (2) to release mineral nutrients in plants for use by other organisms (fig. 2A and B); and (3) to produce the physical character of the soil organic matrix (fig. 1C). In fulfilling these roles, low molecular weight carbon compounds are released and substantial volumes of OM, including decayed wood (fig. 3A and B), are deposited on and in the forest soil (fig. 4A and B). The carbon compounds are metabolized by various groups of soil microorganisms active in nutrient cycling, including the nonsymbiotic (NS) nitrogen-fixing bacteria.

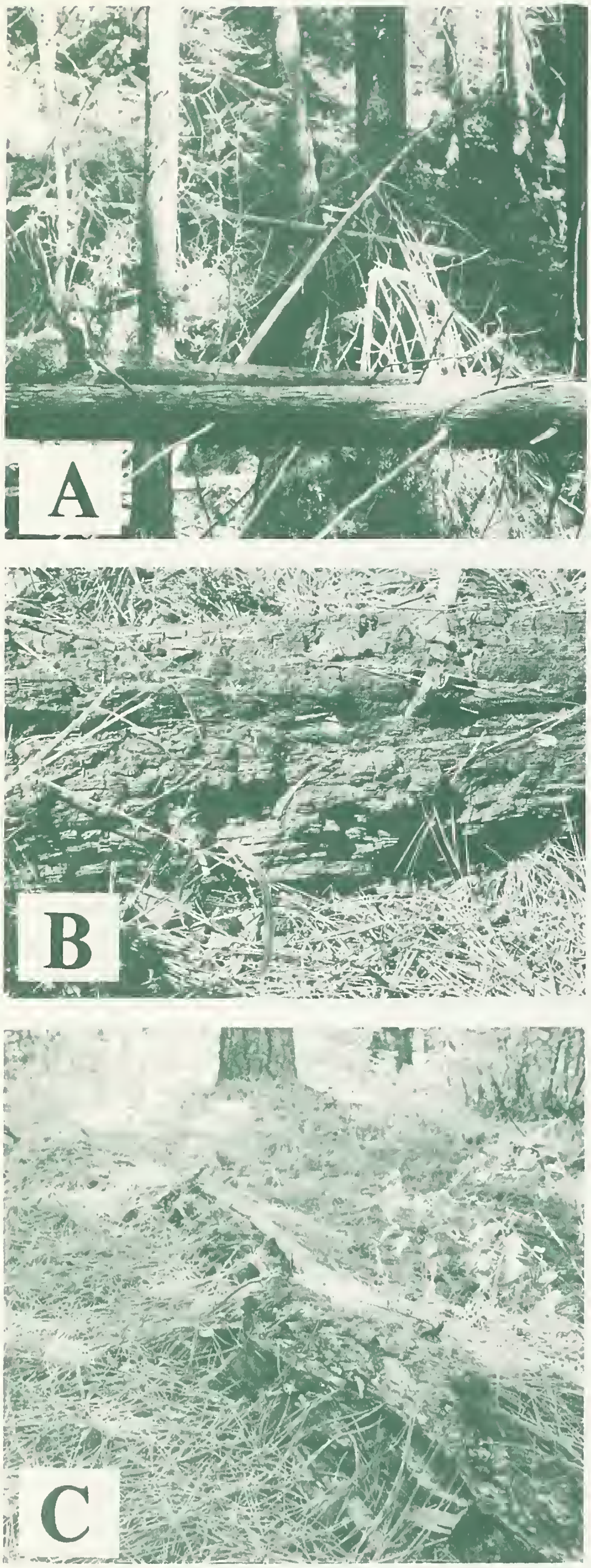

Figure 1—(A) Natural forest residues are important parent materials that decay in place (B) to form deposits (up to 15 percent of surface soil volume) of decayed wood (C) in forest soils.

Figure 2—(A) *Phellinus pini* (Thore ex Fr.) Lloyd, an important heart rot fungus of living trees that produces rot columns inhabited by active populations of nonsymbiotic N-fixing bacteria; (B) *Fomitopsis pinicola* (Swartz ex Fr.) Karst., an important slash decay fungus that produces a brown, cubicle rot product that supports highly active populations of nonsymbiotic N-fixing bacteria.

The decayed soil wood forms long-lasting, high moisture microsites (Larsen and others 1980; Place 1950) important as an environment for NS-N fixation and for symbiotic ectomycorrhizal associations between certain fungi and conifer feeder roots (Harvey 1982; Jurgensen and others 1979).

Because forest soils of the Inland Northwest are frequently N limited (Pregitzer 1984) potential natural sources of N accretion in soils are important for continued productivity. There are only three natural sources: (1) precipitation, or N fixed by electrical discharge (lightning) and N in dust particles, pollen, or air pollutants; (2) symbiotic N fixation by legumes and other nodulated plants (for example, *Alnus, Ceanothus, Lupinus*) containing sym-

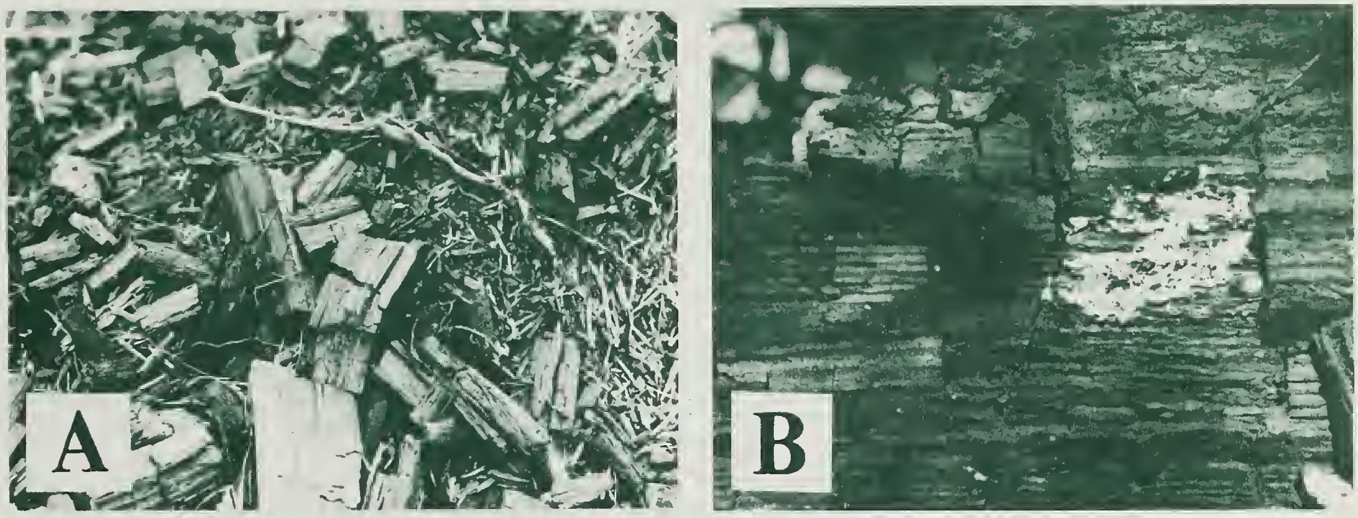

Figure 3—(A) Brown, cubicle, decayed wood frequently occurs as substantial deposits on and in forest soils; these deposits persist (at least 550 years) long after any resemblance to a decayed log remains; (B) Even in early stages of decay, the brown cubicle nature of the decay product produced by certain fungi (for example, *F. pinicola*) is evident; note active fungal growth that represents the early stage of fruiting body formation.

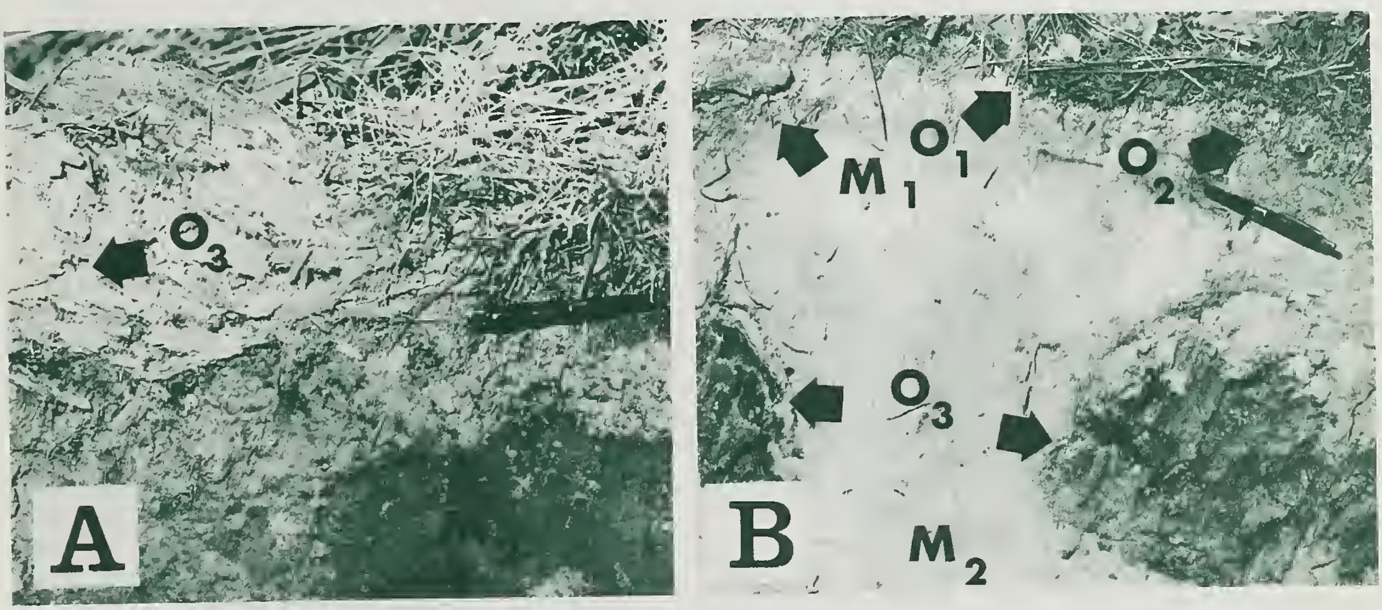

Figure 4—(A) Soil profile (cross-section) containing a surface deposit (old log) of decayed wood partially incorporated into the upper horizons; (B) profile containing deep deposits (old roots) of decayed wood in soil. Note that the primary organic-containing horizons—layers of litter (O_1), humus (O_2), decayed wood (O_3), and surface mineral base (M_1), with the exception of old roots—occur above the pen in both photos. These shallow horizons represent 60 to 70 percent of the stored N in these soils (table 2). Thus, the 5-30 cm mineral horizon (M_2) contains a relatively small portion of the stand N.

biotic associations with N-fixing bacteria (Gordon and others 1979); and (3) nonsymbiotic N fixation by free-living, N-fixing bacteria that occur in soil and plant residues (Jurgensen and others 1979). The energy source for N fixation by symbiotic bacteria is provided by the living host plant. Nonsymbiotic bacteria get their energy from the simple carbon compounds released from OM and plant residues by decay fungi (fig. 2A and B, fig. 3B). Although symbiotic N-fixation is the most efficient process, most ecosystems in the Inland Northwest have few nodulated species, particularly in the absence of historical fire (Gruell 1986), and therefore, the ecosystems rely primarily on nonsymbiotic sources of nitrogen (Jurgensen and others 1979).

The symbiotic association between conifer roots and fungi (ectomycorrhizae) is another important microbial activity for functioning forest ecosystems (Robinson 1967; St. John and Coleman 1983). Again, as was the case for symbiotic N fixers, this is an invasive association wherein the energy for microbial metabolism is contributed by the host plant (Hacskaylo 1973). In this case, the fungus is not involved in fixing N. Rather, it improves the ability of tree root systems to extract fixed N and water from the soil (Bowen and Smith 1981; Harley 1978). This association is also an effective aid for acquiring other nutrients, particularly phosphorus (Harley 1978; Morrison 1962). Thus, it is an important aid to tree growth in infertile soils. Both mycorrhizal and N-fixing associations form varied but distinctive structures on root systems (short roots and nodules, respectively) and make a direct contribution to the growth of the host plant (Gordon and others 1979; Trappe and Strand 1969).

Another microbial action of varying importance is the association among conifers and aggressive root and stem decay fungi that cause disease. Although the products of the disease process, in the form of decayed and decaying wood, form an environment conducive to NS-N-fixing organisms (fig. 2A) (Harvey and others in preparation), the cost in tree mortality and wood loss can be high. In this case, the disease fungi contribute directly to reduced performance of the individual host even though, in the long term, the nitrogen fixed is utilized by the next generation. In most cases, the potential for nitrogen input from diseased tissue appears relatively small.

THE NATURE OF THE SOIL

Forest soils of the Inland Northwest are usually Inceptisols. However, they contain five easily recognized components: (1) the litter layer, consisting of recognizable plant debris (leaves, etc., designated as the O_1 or O_i horizon); (2) the humus layer, consisting of dark, extensively decayed and disintegrated organic detritus (designated as the O_2, or O_e, and O_a horizon)—forest floor is a term that refers to the combined humus and litter layers; (3) decayed wood, consisting of the usually brown colored crumbly mass of residual lignin left from decaying woody material that has been incorporated into the soil; (4) charcoal, or extensively charred wood mixed in soil as a result of historical fire activity; and (5) the mineral soil material. We usually separate the mineral soil into two strata based on OM content. The surface 5 cm of mineral soil is a transition layer that occurs immediately below the humus layer. It tends to have incorporated humic materials. The mineral soil below this surface layer has a low organic content, normally less than 5 percent, and a higher bulk density (fig. 4A and B).

Each of the soil horizons or soil components listed above supports specific microorganisms and rooting activities that usually improve the soil quality as a medium for tree growth. Each component has a unique chemical and physical character based on its organic content, physical layering, and nature of underlying parent materials. In our discussion, we will concentrate on the surface 30 cm, particularly the organic mantle, because most conifer roots are there (Kimmins and Hawkes 1978), and it is easily disrupted or destroyed by forest management activities. If extensively disrupted, removed, or destroyed, drastic reductions of growth, perhaps to the point of deforestation, can result (Hayes 1970; Weber and others 1984). However, deeper soil horizons may also be important to tree growth, especially on dry, sandy soils (Van Rees and Comerford 1986).

BASIC FUNCTIONS OF THE SOIL ORGANIC MANTLE

The organic and mineral components that make up the soil mantle have a variety of physical and chemical characteristics important to biological processes (Larsen and others 1980). Dead plant bodies tie up substantial quantities of nutrients, tend to retain large quantities of moisture, and can restrict air, sunlight, and large animal movement. Chemical energy bound in plant carbon compounds fuels important microbiological activities that represent major factors in the physical development of soils, in plant nutrition, and in the spread of insects and diseases (USDA FS 1980).

Organic detritus buried in the soil profile improves aeration, increases structure, infiltration, percolation, and retention of moisture, and protects the soil from compaction (Lull 1959). Accumulated surface debris and woody residues represent potential fuel for wildfire, an important though sometimes problematical force in the development of Inland Northwest forests and the soils in which they grow (Habeck and Mutch 1973; Harvey and others 1979b). As residues decay they become incorporated into the soil and form an organic reserve (figs. 1C, 3A, and 4A and B). If decay (microbial oxidation) is slow and residue accumulation rapid, fire frequently intervenes. This is usually the case in the Intermountain West (Olson 1963). However, aggressive fire control is moderating recent fire cycles. If wood accumulation is excessive, burn temperatures may be high and organic removal (physical oxidation) excessive. The interactive roles for fire and decay in development of forest stands and soils can be important to site productivity (Harvey and others 1979b).

The amount of OM in Inland Northwest forest soils is usually low. Organic matter makes up less than 15 percent (volume) of the top 30 cm (feeder root zone) of these soils (Harvey and others 1976). As we will demonstrate, this 15 percent normally has the highest concentrations of nutrients, especially nitrogen, has substantial moisture-holding ability and cation exchange capacity (CEC), and supports most of the N-fixing activities and important symbiotic associations (ectomycorrhizae) that contribute directly to tree growth potential.

FOREST PRODUCTIVITY: THE ROLE FOR ORGANIC MATTER BEFORE DISTURBANCE

Perhaps the best way to examine importance of the organic mantle to forest productivity is to catalog organic reserves, examine their nature, and calculate their relative contributions to productivity potential. To do this we will examine three old-growth stands from western Montana

(Harvey and others 1979a) that represent the range of temperature-moisture conditions typical of commercial forests in the Northern Rocky Mountains. We will also examine, in lesser detail, old-growth stands typical of forests in northern Idaho and eastern Washington and second-growth stands in western Montana. Old-growth stands (150 to 250 years) subject to natural fire are useful examples because they represent the culmination of interactions between forest, climate, and soil development processes indicative of a long-term balance between productivity and stability. As such, old-growth stands provide a model with which we can compare ecologically similar, but disturbed systems, to determine if disturbance-related nutrient and OM losses are likely significant to growth potential, and how long reconstitution (repair) may take (Clayton and Kennedy 1985).

Most stands reviewed here have been discussed in detail elsewhere (Harvey and others 1981a, 1981b, 1979b; Jurgensen and others 1984; Larsen and others 1978) or are referenced with respect to appropriate habitat type or habitat series for which extensive vegetative descriptions are available (Daubenmire and Daubenmire 1968; Pfister and others 1977). Therefore, we will not attempt to further describe our model stands here.

Nutrient Distribution

Because most forest stands and soils of the Inland Northwest tend to be N limited, sources for N and N reserves (stored N or N pool) can limit productivity. Table 1 shows the organic components contained in the three old-growth Northern Rocky Mountain forests, and the relative rates, amounts, and proportions of nonsymbiotic N fixation associated with them. Sound stem wood and foliage are not considered until the recycling (decay) process begins with deposition on the forest floor. Table 2 shows the total and proportional distribution of nitrogen stored in these organic components.

It is apparent that decaying on-site residues and decayed wood in soil are particularly important as sources for nitrogen input and storage. The proportional distribution of these important N properties among the organic components subject to loss by displacement, removal, or burning indicates that most N cycling in forest soils is directly associated with surface organic materials (fig. 4A and B). Thus, organic reserves are critical to the N-based productivity of these sites, and they are highly vulnerable to potential loss (tables 1 and 2).

This is not all of the story. How N and other nutrients are distributed and exchanged within the soil and between the soil and aboveground components of a forest stand can also alter productivity (Meier and others 1985; Swank and Waide 1980; Vitousek and others 1982). For example, cold ecosystems, particularly cold-wet ecosystems, tend to accumulate N in organic components, sometimes to the detriment of productivity (low decay rate combined with long fire intervals) (Keeney 1980). However, we will emphasize N input (primarily fixation) and N storage in the soil and residue.

As with nitrogen, phosphorus is also concentrated in OM (table 3). However, phosphate is much less frequently in short supply and less subject to fire-induced losses than N.

Table 1—Estimated organic materials (OM) reserves and nonsymbiotic nitrogen fixation rates and amounts associated with residues and soil components of three old-growth forests representative of the Northern Rocky Mountains

Component	Organic content	N-fixation rate[2]	N-fixation amount	Percent of site total	Percent[1] N fixation vulnerable
	mg/ha	g^{-9}*/g/day*	*g/ha/yr*		
Pseudotsuga menziesii/Physocarpus malvaceus[3] (Douglas-fir/ninebark)					59
Residue	45.1	18.7	160	21	
Soil wood	37.0	9.0	94	12	
Forest floor	26.3	11.1	93	12	
Mineral, 0-5 cm	29.1	.8	106	14	
Mineral, 5-30 cm[4]	73.4	.6	320	41	
Abies lasiocarpa/Clintonia uniflora (subalpine fir/clintonia)					76
Residue	145.7	21.5	515	40	
Soil wood	35.9	16.9	161	13	
Forest floor	36.0	19.5	197	15	
Mineral, 0-5 cm	26.1	1.0	106	8	
Mineral, 5-30 cm	85.8	.7	305	24	
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)					67
Residue	83.2	15.9	230	26	
Soil wood	50.5	9.3	120	14	
Forest floor	49.7	10.2	125	14	
Mineral, 0-5 cm	29.3	.9	117	13	
Mineral, 5-30 cm	68.6	.7	290	33	

[1]Amount of nitrogen-fixing capacity associated with surface OM depth subject to displacement or volatilization in harvesting and site-preparation operations.
[2]Theoretical conversion ratio of acetylene reduction to nitrogen fixation 3:1.
[3]Habitat type (Pfister and others 1977).
[4]Mineral soil to 30 cm total depth.

Table 2—Estimated nitrogen reserves associated with residues and soil components of three old-growth forests representative of the Northern Rocky Mountains

Component	Organic content	Nitrogen	Total pool	Percent of total	Percent[1] N storage vulnerable
	mg/ha	*Percent*	*kg/ha/N*		
Pseudotsuga menziesii/Physocarpus malvaceus[2] (Douglas-fir/ninebark)					56
Residue	45.1	0.15	68	3	
Soil wood	37.0	.72	419	16	
Forest floor	26.3	.84	438	17	
Mineral, 0-5 cm	29.1	.07	543	21	
Mineral, 5-30 cm[3]	73.4	.04	1,162	44	
Abies lasiocarpa/Clintonia uniflora (subalpine fir/clintonia)					62
Residue	145.7	.15	219	9	
Soil wood	35.9	.65	344	14	
Forest floor	36.0	.85	570	24	
Mineral, 0-5 cm	26.1	.06	343	14	
Mineral, 5-30 cm	85.8	.04	908	38	
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)					64
Residue	83.2	.15	125	5	
Soil wood	50.5	.52	341	14	
Forest floor	49.7	.96	787	33	
Mineral, 0-5 cm	29.3	.04	264	11	
Mineral, 5-30 cm	68.6	.04	867	36	

[1]Amount of nitrogen pool associated with surface organic materials (above M_2 horizon) subject to displacement or volatilization in harvesting and site preparation operations.
[2]Habitat type (Pfister and others 1977).
[3]Mineral soil to 30 cm total depth, the feeder root zone.

Table 3—A summary of chemical and physical properties of soils from two old-growth forests representative of the Northern Rocky Mountains

	Physical properties								Chemical properties[1]					
	Texture													
Stand	Sand	Silt	Clay	Classification	Field capacity	Wilting point	Organic materials	Cation exchange capacity	pH	N	P	Ca	Mg	K
	- - - Percent - - -				- - - - - - - - Percent - - - - - - - -			*meq/100 g*		- - - - - - - - - Percent - - - - - - - - -				
Pseudotsuga menziesii/Physocarpus malvaceus[2] (Douglas-fir/ninebark)														
Litter	—	—	—		—	—	69.0	—	5.4	1.08	0.26	2.19	0.14	0.12
Humus	—	—	—		101.2	71.5	46.9	—	5.9	.79	.24	1.39	.16	.12
Soil wood	—	—	—		198.7	128.0	63.4	—	4.9	.72	.14	1.04	.09	.07
												- - - *meq/100 g* - - -		
Mineral-trans	42	45	13	loam	27.8	8.7	8.6	35.0	5.5	.16	.02	17.8	1.7	0.6
Mineral-30 cm	46	40	14	loam	30.8	5.7	5.1	18.7	5.7	.08	.01	10.6	1.4	.4
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)												- - - - *Percent* - - - -		
Litter	—	—	—	—	—	—	78.5	—	5.1	.91	.29	1.42	.10	0.11
Humus	—	—	—	—	138.4	120.6	56.6	—	4.7	.97	.29	1.15	.13	.11
Soil wood	—	—	—	—	179.5	137.1	70.3	—	4.5	.52	.11	.84	.07	.11
												- - - *meq/100 g* - - -		
Mineral-trans	47	40	13	loam	26.3	8.6	7.8	15.1	5.8	.07	.02	11.5	1.0	0.3
Mineral-30 cm	47	39	14	loam	29.3	9.6	5.5	12.6	6.3	.07	.01	8.1	1.0	.3

[1]Organic samples are expressed as total amounts. Mineral samples are expressed as: available P, Ca, Mg, and K as exchangeable.
[2]Habitat type (Pfister and others 1977).

Phosphorus is a part of parent minerals and not easily volatilized. It can, however, be tied up and rendered unavailable in certain volcanic ash soils. Other nutrients are more evenly distributed in the soil profile and even less subject to loss. Sulfur, like nitrogen, can be volatilized, but sulfur is a component of soil minerals and an important air pollutant (as opposed to biologically fixed N) not often in short supply nor subject to heavy loss, as is the case for N.

It should be noted that fire-caused losses of N can be overestimated. If calculations are based only on losses of specific organic components, estimates may be high.

However, if the entire soil profile is considered, N levels may increase in deep soil horizons after a fire. Apparently the cool, moist, mineral soil can act as a condenser that captures a portion of the N volatilized from the forest floor (Mroz and others 1980). Nitrogen losses associated with a moderate prescribed burn (*Abies lasiocarpa/Clintonia uniflora* habitat type) after clearcutting in western Montana were estimated at only 6 percent of the total in the surface 30 cm of soil (Jurgensen and others 1981). (A moderate fire is herein considered representative of flame lengths from 1 to 2 m, as described by Ryan and Noste (1985), with the temperature at the mineral soil surface not exceeding 150 °C.) However, these losses would likely be much larger from a wildfire during extremely dry conditions, when the upper mineral layer is dry and easily heated (Grier 1975).

Rooting Activity

It is appropriate now to examine distribution of the primary plant organs (feeder roots and ectomycorrhizal short roots) responsible for extracting nutrients from the soil system. Table 4 shows the distribution of ectomycorrhizal short roots among soil components from the same three stands used to evaluate nutrient distribution. As was the case with N, there is a disproportionate concentration of ectomycorrhizae in the organic components. Proximity of mycorrhizae to nutrient supplies likely enhances uptake efficiency (St. John and Coleman 1983). Also, fine root and ectomycorrhizal turnover contributes directly to OM and nutrient cycling and accumulation in upper soil horizons (Fogel and Hunt 1983; Vogt and others 1980).

Table 4—Proportion of soil volume represented by various soil components and proportion of ectomycorrhizal root tips found in respective soil component[1]

Soil component	Soil volume	Ectomycorrhizae distribution	Average number of ectomycorrhizal tips
	Percent	*Percent*	*Tips/core*
Pseudotsuga menziesii/Physocarpus malvaceus[2] (Douglas-fir/ninebark)			
Litter	1	14	9
Decayed wood	7	33	20
Humus	11	30	19
Mineral soil	81	23	14
			62
Abies lasiocarpa/Clintonia uniflora (subalpine fir/clintonia)			
Litter	2	0	0
Decayed wood	13	19	19
Humus	12	74	74
Mineral soil	73	7	7
			100
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)			
Litter	4	6	34
Decayed wood	16	51	297
Humus	12	32	187
Mineral soil	68	11	62
			580

[1]To 30 cm depth, that is, feeder root zone as determined by random soil core sampling, 50 cores per stand, from three old-growth stands (250 years) representative of the Northern Rocky Mountains.
[2]Habitat type (Pfister and others 1977).

Table 5—Proportional volume of soil components and proportion of 100 natural seedlings (each site) with more than half of their root system in respective soil component, from three old-growth stands representative of the Northern Rocky Mountains

Soil component	Soil component volume[1]	Root system distribution[2]
	Percent	*Percent*
Pseudotsuga menziesii/Physocarpus malvaceus[3] (Douglas-fir/ninebark)		
Moss[4]	—	0
Soil wood	7	71
Humus	11	25
Mineral soil	82	4
Abies lasiocarpa/Clintonia uniflora (subalpine fir/clintonia)		
Moss	—	0
Soil wood	14	46
Humus	14	49
Mineral soil	72	5
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)		
Moss	—	8
Soil wood	17	39
Humus	12	48
Mineral soil	71	5

[1]Includes soil depth to 30 cm, primary feeder root zone; seedling root systems averaged approximately 14 cm depth.
[2]Seedling included as representing a soil component if more than 50 percent of its root system was in that component. Seedling species primarily Douglas-fir, subalpine fir, western hemlock, and western redcedar.
[3]Habitat type (Pfister and others 1977).
[4]Data not available, estimated less than 1 percent.

In table 5 we show data from randomly selected, successful natural seedlings, again under these same stands. These seedlings were sampled by digging them up, following their root systems, and recording ectomycorrhizal distribution among the various soil components (Harvey and others 1987). Results were almost identical to the distribution of ectomycorrhizae on root systems of the older trees. Thus, both the occurrence of ectomycorrhizal activities and the distribution of feeder roots from conifers, young or old, are concentrated in soil OM. So both the nutrients and the means of acquiring them are highly dependent on the presence of organic components in old-growth systems.

Changing Sites

There is an obvious effect of site on the role of OM where there is a history of or high risk for insect, disease, or animal predation problems. Tree litter has the potential to increase damage caused by these organisms and to contribute to further spread of the problem (Fellin 1980). Even if problem organisms are not causing damage, litter may still contribute to the development of damage by providing an environment that attracts insects or animals, or

that supplies inoculum sources for pathogenic fungi (Fellin 1980; Nelson and Harvey 1974; Ream and Gruell 1980).

Although less conspicuous, the relative importance of a soil organic mantle in supporting beneficial microorganisms on different sites is also subject to change. This is the case for both NS-N fixation and ectomycorrhizal activities. For example, table 1 shows the rate of N input (fixation) potential is less on the dry site (*Pseudotsuga menziesii/Physocarpus malvaceus*) than on more moderate sites (*Abies lasiocarpa/Clintonia uniflora* and *Tsuga heterophylla/Clintonia uniflora*). Similarly, the numbers of ectomycorrhizal roots in the soil reflect relative harshness and productivity potential (table 4). Also, if we specifically examine the role of soil wood in supporting root development, we find that the relative importance of this component to dry sites can be much greater than to moist sites (table 5). Thus, there is the potential for the soil OM to be most important to sites on which it is the most difficult to produce (low productivity sites).

FOREST PRODUCTIVITY: THE ROLE FOR ORGANIC MATTER AFTER DISTURBANCE

Although the role for soil OM in forest productivity after disburbance is similar to before, several minor alterations can occur. These changes are mediated primarily through rapid release of nutrients from organic horizons caused by stand opening (fertilization effect), changes of stand species composition, displacement or loss of OM potential needed for regeneration or developing young stands, and the effects of competing vegetation.

The data in this section come largely from studies of subalpine fir and Douglas-fir habitat series typical of northern Idaho and western Montana.

The Fertilization Effect

Perhaps most obvious of postdisturbance changes is the resulting fertilization effect. When the stand is opened due to harvesting, fire, or wind, soil temperature and moisture levels increase (Hungerford 1980; Larsen and others 1980), resulting in acceleration of OM decomposition by microbes, or pyrolysis in the case of fire, which releases nutrients tied up in undecayed OM (Jurgensen and others 1979). This effect is shown in table 6 for mineral N and pH. All nutrient concentrations returned to preharvest levels within the second year after disturbance, except for pH, which remained high for at least 4 years after burning (Jurgensen and others 1981). Nutrient concentrations and distribution do not change radically unless disturbance is severe. In the case of severe disturbances, either fire (Niehoff 1985) or mechanical (Nielson-Gerhardt 1986) changes can be extreme. Obviously, large removals of nitrogen and significant losses of OM-derived cation exchange capacity are possible.

Changing Species Composition

Another potential concern after disturbance involves changes in species distribution; climax conifer species may be replaced by pioneer and seral species. Species suited for early ecosystem development may be better adapted to a low OM soil. Although this may well be the case, table 7 shows that young, disturbed stands utilize soil organic components as a substratum for supporting ectomycorrhizal activity much as older stands do. In the stands studied, the primary species are pioneer—western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*Pinus contorta* Dougl.)—and the youngest stands, 12 and 16 years, were extremely low in organic reserves. In the case of the 12-year-old lodgepole pine stand, organic components made up only 5 percent of the feeder root zone, but still

Table 6—Microbial and chemical characteristics of a forest soil impacted by management activities. Measurements taken the spring following disturbance, a minimum of 50 random cores per treatment. All stands depicted represent comparable subalpine fir (*Abies lasiocarpa/Clintonia uniflora*)[1] forests representative of the Northern Rocky Mountains.

	Nature of stand				
Soil or microbial character	Undisturbed	Partial cut	Partial cut, broadcast burn	Clearcut	Clearcut, broadcast burn
Active ectomycorrhizae (No. tips/liter) (all soil components)	600	175	40	1	0
Nitrogen fixation rate (g/ha/day) (all soil components)	22	ND[2]	ND	16	9
Ammonium nitrogen (μg/g) (humus only)	25	ND	ND	40	75
Nitrate nitrogen (μg/g) (humus only)	8	ND	ND	9	12
pH (humus only)	5.6	ND	ND	6.2	7.5[3]

[1]Habitat type (Pfister and others 1977).
[2]Not determined.
[3]Acidity remained low for at least 4 years; other chemical characteristics returned to predisturbance levels by the end of the growing season.

Table 7—Proportion of soil[1] volume represented by various soil components and distribution of ectomycorrhizal root tips found in soil components[2]

Soil component	Soil volume	Distribution of ectomycorrhizae
	Percent	
Intermediate-aged stand (52 yrs)—lodgepole pine		
Litter	3	10
Soil wood	4	57
Humus	11	15
Mineral soil	83	18
Young stand (16 yrs)—western larch		
Litter	3	1
Soil wood	5	8
Humus	5	23
Mineral soil	87	68
Young stand (12 yrs)—lodgepole pine		
Litter	2	0
Soil wood	1	40
Humus	2	36
Mineral soil	95	24

[1]To 30 cm depth, the feeder root zone.
[2]A minimum of 50 random cores and 100 random seedlings per stand. From three disturbed stands representative of the subalpine fir/clintonia habitat type (Pfister and others 1977) of the Northern Rocky Mountains.

supported 76 percent of the ectomycorrhizal activity (table 7). The large relative contribution of OM, particularly soil wood, to support ectomycorrhizae on the lodgepole pine-dominated sites, and smaller contribution on the western larch site, may be indicative of a species effect.

Regeneration

To examine an earlier stage of postharvest forest development we used the results of a postlogging and burning regeneration study in the Crowsnest Forest of Canada, just north of Glacier National Park, MT (Day and Duffy 1963). Table 8 shows that organic soil components can act as valuable seedbeds in the Canadian Rockies. Although we normally expect mineral soils to provide superior seedbeds, this is not always the case (Haig and others 1941; Minore 1972). Day and Duffy indicated that lodgepole pine more frequently utilizes mineral seedbeds than do Engelmann spruce (*Picea engelmannii* [Parry ex Engelm.]) or Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), another indication of a species effect. However, in all of the instances referred to, the organic mantle continues to play an important role in both disturbed and regenerating forests.

Table 8—Seedbed composition and natural seedling distribution from logged-over stands in the Crowsnest Forest in Canada[1]

Seedbed	Area	Seedling distribution
	Percent	
Muck	—[2]	9
Litter	11.8	9
Moss	6.3	24
Decayed wood	16.5	24
Humus	44.9	12
Mineral soil	20.4	22

[1]Seedling species are Engelmann spruce, Douglas-fir, and lodgepole pine. Most stands represent subalpine fir habitat series. After Day and Duffy (1963).
[2]Data for area not available.

Competition and Early Stand Development

At this point, discussion of interactions between conifers and nonconifers, as they may impact the relative ability of each to grow, is largely premature. However, it is interesting to speculate that destruction of soil organic reserves by repeated wildfires over the last 75 years may have contributed to the development of many aggressive shrubfields in northern Idaho. Repeated (often severe) wildfires were particularly common in the Northern Rocky Mountains early in this century (Wellner 1970).

Reforestation processes may require long-term reconstitution of organic horizons and nitrogen reserves for young conifers to be competitive with the other vegetation. A specific observation we have made regarding soil wood and competition is that, despite prolific rooting of conifers in this substratum, few roots of other plants are found. Thus, soil wood may provide a selective substratum for conifer roots. We have frequently noted selective occurrence of seedlings associated with deposits of decayed wood throughout the Inland Northwest, particularly on harsh sites (fig. 1C, fig. 5). Current research is emphasizing the interactive roles of soil components and site preparation as they affect reforestation.

Figure 5—Young Douglas-fir seedlings, and other conifers, are frequently observed in and associated with old logs and soil wood deposits.

THE MANAGEMENT OPPORTUNITY

Protection or enhancement of the forest soil's organic mantle, via manipulation of woody residues and other organic soil components, provides a major tool for impacting growth in forest ecosystems. In many ways manipulation of the organic constituents of soils is the only practical tool available for mitigating effects of harvesting systems that remove most of the standing crop or that cause extensive soil disturbance. Tree growth in Inland Northwest forest ecosystems can be dependent on the ability of a soil to retain moisture and to support N-fixing and ectomycorrhizal organisms. This ability, in turn, is largely dependent on the presence of an adequate organic base. Thus, large losses of OM from thin or infertile soils are likely to result in substantial losses of productivity. This leads to the other obvious questions: how much OM and of what kind do we need to protect the productivity of our forest soils?

How Much

There can be too much as well as too little OM on the soil surface. Too much may lead to excess fuel loading and high fire risks that, in turn, may lead to too little. All organic soil constituents decay, and presumably more decay increases the associated N input and potential for productivity. Because part of that productivity (the high-risk fuel component) may carry great risk, we must stay within fuel management guidelines if we are to deliberately enhance the organic mantle. Thus, possible management of N input, via N-fixation through residue manipulation, is at least limited by risk of fire.

The other major beneficial microbial activity, ectomycorrhizal infection, particularly in infertile soils, can also be useful in establishing management targets for adjusting OM composition of forest soils. By dividing soil samples containing ectomycorrhizae according to the quantity of OM they contain, and then relating organic percentage to ectomycorrhizal activities, we were able to provide estimates for the question of quantity of organics desired. Our initial recommendation of 22.4 metric tons/ha was based on a large data set from the three western Montana sites (Harvey and others 1981a).

Let's reexamine how this recommendation was derived and see how well it holds for two productive northern Idaho sites and a moisture-limited, harsh site from eastern Washington. Table 9 shows the relationship between organic percentage and ectomycorrhizal activity. Optimal activity on all six sites occurred between 15 and 45 percent OM content. In no case were additional benefits realized from organic levels in excess of 45 percent of the surface 30 cm of soil. On the other hand, there were reduced activities, in all cases, when organic volumes in the surface 30 cm of soil were less than 15 percent.

By conservatively assuming that a substantial portion of the soil OM required to support future stand growth will be derived, at least indirectly, from woody residues, we can calculate a theoretical residue loading based on the 31 to 45 percent figure and see if the result is reasonable and meets potential fuel loading limits. By assuming a 40 percent loss of volume from the time a log becomes fresh residue to when it begins functioning as a soil component (based on field observations), and converting the percentage figure to volume, then to weight, we find a soil minimum of 22.4 metric tons/ha. Add 12 metric tons/ha for suspended residues in an advanced state of decay but not yet incorporated in the soil, and we have a recommended 22 to 36 t/ha. This figure is well within fuel management guidelines. Due to the general infertility of Inland Northwestern forest soils, we would not generally recommend removing foliage or small twigs (because of their relatively high nutrient content) from most forested sites (Stark 1980). This would be particularly true of the cold, infertile ecosystems characteristic of the eastern slopes of the Central and Northern Rocky Mountains (Harvey and others in press; Yavitt 1984).

The general recommendation cited above seems appropriate for all six sites shown in table 9, but with reservations for the extreme dry and moist ends of the moisture gradient represented. On the moist end the ability of OM to absorb and hold water may create a situation of excess moisture and lower soil temperatures where deposits are heavy. Therefore, because these sites are productive and should replace lost organic horizons quickly, we do not consider them sensitive. On the other hand, replacement of OM on dry sites will take place slowly, so they can be considered extremely sensitive to loss of organic soil components.

The ponderosa pine site requires further clarification. High levels of OM on this site were not effective in supporting ectomycorrhizal roots, though high organic levels were effective on the dry Douglas-fir site. We interpret this as an indication moisture was so limiting on the

Table 9—Relationship of active ectomycorrhizal root tips (percentage of total) to soil organic matter content (50 random cores per site from undisturbed stands)

Location	Series[1]	Organic matter volume (percent)			
		0-15	16-30	31-45	>45
		Percent			
Western Montana	Douglas-fir, series dominated by Douglas-fir	7	36	52	5
	Subalpine fir series, dominated by subalpine fir and spruce	12	58	27	3
	Western hemlock series, dominated by western hemlock	13	45	23	19
Northern Idaho	Western hemlock series, dominated by western redcedar[2]	20	49	21	10
	Western hemlock series, dominated by western white pine	12	20	41	27
	Ponderosa pine series, dominated by ponderosa pine	38	44	18	—[3]

[1]Climax type as defined by Pfister and others (1977).
[2]Western redcedar is largely nonectomycorrhizal; mycorrhizae are from the hemlock component.
[3]Organic matter volumes this high did not occur.

ponderosa pine site that the organic mantle usually does not contain sufficient moisture during the growing season to maintain itself above the permanent wilting point. Thus, we do not think high levels of OM are a problem in this case, except as a potential wildfire hazard. Rather, the OM horizons have an extremely limited period (late spring) to be effective.

Although the above interpretations are derived primarily from old-growth models, it is worthy of note that distribution of ectomycorrhizal activity shows similar patterns in second-growth stands (table 7) and for natural regeneration (Harvey 1982; Harvey and others 1987; Vogt and others 1980). Thus, pioneer or seral species may do better than climax species in low soil OM situations, but we should expect their performance to improve in high OM soils.

What Kind

In the Inland Northwest, forest soils we examined have a ratio between soil humus and soil wood volume that is about equal—1:1 (see organic content in table 1). Both soil components contain substantial quantities of nutrients and both retain moisture well. Wood deposits tend to be large (remains of old logs and roots) so they are effective in moisture storage. Litter and humus, on the other hand, occur in shallow, sometimes discontinuous layers that dry quickly (fig. 4A and B). Each organic component also has unique characteristics with respect to nitrogen relationships. For example, decaying woody residues and decayed soil wood are more effective than other organic materials for supporting high levels of NS, N-fixing activities (table 1), and the forest floor has a greater role for retaining (storing) fixed nitrogen and adsorbing cations than do woody materials (table 2). A similar contrast occurs with ectomycorrhizal activities. In periods of adequate moisture, humus supports the highest levels of ectomycorrhizae but, during periods of drought, soil wood becomes the most active site (Harvey 1982; Harvey and others 1979a; Larsen and others 1982). Thus, we recommend that litter, humus, and woody materials all be carefully maintained in forest soils. This reemphasizes that smaller woody residues and foliage not be removed. They are converted to humus rapidly and contain relatively high quantities of nutrients.

Concerning the conversion of woody residue into the soil wood component, we must consider tree species distribution. We have identified the species of wood contained in the soil of four ecosystems of the Inland Northwest area. Table 10 shows the distributions of species of soil wood found on those sites. These wood identifications indicate that Douglas-fir, western larch, western white pine (*Pinus monticola* Dougl.), and lodgepole pine are the most effective species for producing highly persistent, brown rotted soil wood. Ponderosa pine is also effective (field observations) but did not occur on these sites. Other species, such as western redcedar (*Thuja plicata* Donn ex D. Don), grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), subalpine fir, and Engelmann spruce, usually decay into white, stringy, fibrous materials that do not persist as distinct deposits. Thus, we would add to our residue requirement that, if possible, the 24 to 36 metric tons/ha be of one of the more effective species—preferably Douglas-fir, but western white pine and western larch also appear acceptable.

Table 10—Species distribution of decayed wood in soils of four old-growth forests representative of the Northern Rocky Mountains[1]

Habitat series[2]	Total samples	Species[3] DF	WWP	WL	LPP	WH	SAF	ES
		Percent						
Western Montana								
Douglas-fir	22	100	0	0	0	0	0	0
Subalpine fir	101	77	0	8	3	2	6	4
Western hemlock	16	63	0	0	6	19	6	6
Northern Idaho								
Western hemlock	153	45	49	16	1	4	1	2

[1]Random samples. Number varies according to wood presence and sampling history.
[2]Climax type as described by Pfister and others (1977).
[3]Species codes are DF = Douglas-fir, WWP = western white pine, WL = western larch, LPP = lodgepole pine, WH = western hemlock, SAF = subalpine fir, and ES = Engelmann spruce.

How Long

What would happen if excessive site degradation, through loss of organic reserves, should occur? How long would it take for the ecosystem to rebuild its potential productive capacity? This has been a difficult question because soil development is a dynamic process in which nutrients and carbon circulate between the aboveground and belowground components and within the soil system itself. Methods for estimating time for organic horizon accumulation are crude. However, we used three systems for calculating OM (wood) cycling time, and all produced similar results.

The most straightforward approach is to measure the age of decaying wood by C^{14} analysis. The most likely source of error with this method is an underestimation of age from contamination of the sample with organic materials of recent origin. Table 11 shows that the C^{14} age of soil wood varies from 246 to 473 years, depending on habitat type (Harvey and others 1981b). Another source of error with this method is the possibility that soil wood will persist longer on gentle slopes due to lack of downslope soil movement and resultant breakup of wood deposits. This is probably the reason for older wood on the hemlock/clintonia habitat type.

Another means of calculating site recovery time is to measure N content in the wood components and divide the total by the indigenous N fixation rate. Residue N recovery time (not yet buried in the soil) was similar to the C^{14} soil wood age estimate using this calculation. Soil wood was not useful because of N import from other soil components. Recovery times varied from 425 to 543 years (table 11). This method does not include time required to grow the residue, but it also does not account for N in the stem at the time of death, which should compensate for the age factor.

Table 11—Estimated recovery times, assuming total removal of woody residues, from three old-growth forests representative of the Northern Rocky Mountains

Component	Total N associated with component	N-fixation rate associated with component	Recovery time[1]	C^{14} age	Decay age[2]
	kg/ha	*g/ha/yr*	- - - - - - - - - -	*Years* - - - - - - - - - -	
Pseudotsuga menziesii/Physocarpus malvaceus[3] (Douglas-fir/ninebark)					
Residue	68	160	425	—	—
Soil wood	419	94	—	246 ± 90	192
Abies lasiocarpa/Clintonia uniflora (subalpine fir/clintonia)					
Residue	219	515	425	—	—
Soil wood	344	161	—	257 ± 90	274
Tsuga heterophylla/Clintonia uniflora (western hemlock/clintonia)					
Residue	125	230	543	—	—
Soil wood	341	120	—	473 ± 100	172

[1]Assuming all input of nitrogen is based on internal activities.
[2]Estimated age based on productivity and decay rate (Harvey and others 1981b).
[3]Habitat type (Pfister and others 1977).

We also determined recovery time by calculating the ratio of total wood production potential (growth) to quantity of wood present in old-growth ecosystems (Harvey and others 1981b). This method provided estimates from 172 to 274 years (table 11). This method also underestimates age because growth projections did not account for standing decay.

In any case, if OM reserves (particularly woody components) are lost for any reason, it will take at least one rotation, perhaps two, to restore soil productivity potential based on that resource—that is, convert fresh wood residues (fig. 1A) into substantial decayed soil wood deposits (figs. 1C, 3A, and 4A and B).

Distribution Geometry

If we are to manage the soil organic mantle with systems that inevitably cause disturbance, we must consider the distribution as well as the potential loss of this resource. Initially, these materials must support a regenerating forest, that is, young trees with a limited ability to explore the soil system. Therefore, organic materials should be well distributed as well as conserved. Extensive heavy deposits or large areas with little or no OM are not desirable. We should create a mosaic of maximum possible diversity. This will create a situation where the precise balance of organic materials to mineral soil base required to support the desired site-species combination will be available on at least a small percentage of the acres treated, and it will be well distributed. When planting, seedlings should be placed near a source of organic material. Because of difficulty in getting seedling root to soil contact, they should not be placed directly in deep layers of OM.

Woody residues, as the source for decaying soil wood, should also be well scattered over the treated areas. Several logs per hectare could meet the minimum 22.4 metric tons/ha requirement, but it would not be sufficient. We also recommend, as noted earlier, that residues be of appropriate species (Douglas-fir, western larch, pines). Fresh residues should, if possible, be at least 10 to 15 cm in diameter to provide for relatively deep soil wood deposits. Additionally, if the residues contain heartwood, they are more likely to produce brown cubicle rot, which is the most desirable form of soil wood. Distribution can be enhanced by using relatively short pieces if required. There are likely to be interactions between tree species requirement, climate, soil, and site preparation. This is an active and evolving area of research.

A PERSPECTIVE

Although the need to maintain minimum reserves of soil OM may constrain certain harvest management practices, it is likely to do so only in harsh, cool, or dry ecosystems, or in ecosystems with a severe fire or intensive logging history. Many Inland Northwest habitat types contain adequate organic reserves and are not considered highly sensitive to logging damage, and most of our current harvesting systems leave adequate residue. However, full tree harvesting should be used with caution; where possible, branch material should remain on site.

The most likely problem is with extensive site preparation, particularly piling or windrowing that displaces or destroys the forest floor over large areas. Similarly, scalping or furrowing displaces OM, but the area disturbed can be constrained. Such practices should be used with caution and for resolving specific problems (reduction of fuel or competition) on sites likely to be sensitive to OM loss. Where disturbance is necessary, it should be kept to a minimum. From a fire management perspective, extremely hot wildfires are also dangerous to site and soil productivity, particularly with sensitive (harsh) ecosystems. Also, prescribed burning should be carried out with care to assure that the 24-36 metric tons per hectare requirement for residual woody material is maintained after treatment.

Open-grown, short rotation forests (forests with low competition, maximum soil volume per tree, using pioneer or seral species and a potential for understory symbiotic N-fixers), with appropriate vegetation management seems a good biological approach to managing infertile, second-growth forests with low soil OM reserves. However, costs

of achieving these objectives on such sites are likely to be high. Returns from maintaining an adequate soil organic mantle can reduce these costs.

A recognition of the important role the organic soil mantle plays in forest soils will help alleviate and avoid site degradation caused by excessive disturbance. Guiding our actions with the use of a reasonable biological perspective represents an opportunity to maintain or even improve harvested sites and their soils as a firm foundation for future forestry.

REFERENCES

Bowen, G. D.; Smith, S. E. The effects of mycorrhizas on nitrogen uptake by plants. In: Clark, F. E.; Rosswall, T., eds. Terrestrial nitrogen cycles. Ecological Bulletin (Stockholm). 33: 219-232; 1981.

Clayton, J. L.; Kennedy, D. A. Nutrient losses from timber harvest in the Idaho batholith. Soil Science Society of America Journal. 49: 1041-1049; 1985.

Daubenmire, R.; Daubenmire, J. B. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington Agricultural Experiment Station; 1968. 104 p.

Day, R. J.; Duffy, P. J. Regeneration after logging in the Crowsnest Forest. Publication 1007. Calgary, AB: Canadian Department of Forestry; 1963. 31 p.

Fellin, D. G. Relationships in harvesting and residue treatments to forest insect and disease activity. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 335-416.

Fogel, R.; Hunt, G. Contribution of mycorrhizae and soil fungi to nutrient cycling in a Douglas-fir ecosystem. Canadian Journal of Forest Research. 13: 219-232; 1983.

Gordon, J. C.; Wheeler, C. T.; Perry, D. A. Symbiotic nitrogen fixation in the management of temperate forests: Proceedings, National Science Foundation workshop; 1979 April 2-5; Corvallis, OR. Corvallis, OR: Oregon State University; 1979. 401 p.

Grier, C. C. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian Journal of Forest Research. 5: 599-607; 1975.

Gruell, G. [Personal communication.] 1986 June 26. Intermountain Region, Forest Service, U.S. Department of Agriculture, Ogden, UT.

Habeck, J. R.; Mutch, R. W. Fire dependent forests in the northern Rocky Mountains. Quaternary Research. 3: 408-424; 1973.

Hacskaylo, E. Dependence of mycorrhizal fungi on hosts. Bulletin of the Torrey Botanical Club. 100: 217-223; 1973.

Haig, I. T.; Harris, D. P.; Weidman, R. H. Natural regeneration in the western white pine type. Technical Bulletin 767. Washington, DC: U.S. Department of Agriculture; 1941. 99 p.

Harley, J. L. Ectomycorrhizas as nutrient absorbing organs. In: Proceedings: Royal Society of London Series B. 103: 1-21; 1978.

Harvey, A. E. The importance of residual organic debris in site preparation and amelioration for reforestation. In: Site preparation and fuels management on steep terrain: symposium proceedings; 1982 February 15-17; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension; 1982: 75-85.

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J. Residues, microbes, and soil management in cool, east slope Rocky Mountain lodgepole pine ecosystems. In: Management of small stem stands of lodgepole pine: workshop proceedings; 1986 June 30-July 2; Fairmont Hot Springs, MT. [In press].

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J. Organic reserves: importance to ectomycorrhizae in forest soils in western Montana. Forest Science. 27: 442-445; 1981a.

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J.; Graham, R. T. Relationships among soil microsite, ectomycorrhizae, and natural conifer regeneration of old-growth forests in western Montana. Canadian Journal of Forest Research. 17: 58-62; 1987.

Harvey, A. E.; Jurgensen, M. F.; Larsen, M. J.; Jones, E. A. Nitrogen fixation associated with pathological decay of living north Idaho conifers. [In preparation].

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in western Montana. Forest Science. 22: 393-398; 1976.

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. Forest Science. 25: 350-360; 1979a.

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Fire-decay: interactive roles regulating wood accumulation and soil development in the northern Rocky Mountains. Research Note INT-263. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979b. 4 p.

Harvey, A. E.; Larsen, M. J.; Jurgensen, M. F. Rate of woody residue incorporation into northern Rocky Mountain forest soils. Research Paper INT-282. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981b. 5 p.

Hayes, G. I. Impacts of fire on forested ecosystems. In: The role of fire in the Intermountain West. Missoula, MT: Intermountain Fire Research Council; 1970: 99-118.

Hungerford, R. D. Microenvironmental response to harvesting and residue management. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 37-74.

Jurgensen, M. F.; Arno, S. R.; Harvey, A. E.; Larsen, M. J.; Pfister, R. D. Symbiotic and nonsymbiotic nitrogen fixation in Northern Rocky Mountain forest ecosystems. In: Symbiotic nitrogen fixation in the management of temperate forests: proceedings, National Science Foundation workshop; 1979 April 2-5; Corvallis, OR. Corvallis, OR: Oregon State University; 1979: 294-308.

Jurgensen, M. F.; Harvey, A. E.; Larsen, M. J. Effects of prescribed fire on soil nitrogen levels in a cut-over Douglas-fir/western larch forest. Research Paper INT-275. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 6 p.

Jurgensen, M. F.; Larsen, M. J.; Spano, S. D.; Harvey, A. E.; Gale, M. R. Nitrogen fixation associated with increased wood decay in Douglas-fir residue. Forest Science. 30: 1038-1044; 1984.

Keeney, D. R. Prediction of soil nitrogen availability in forest ecosystems: a literature review. Forest Science. 26: 159-171; 1980.

Kimmins, J. P.; Hawkes, B. C. Distribution and chemistry of fine roots in a white spruce-subalpine fir stand in British Columbia: implications for management. Canadian Journal of Forest Research. 8: 265-279; 1978.

Larsen, M. J.; Harvey, A. E.; Jurgensen, M. F. Residue decay processes and associated environmental functions in Northern Rocky Mountain forests. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 157-174.

Larsen, M. J.; Jurgensen, M. F.; Harvey, A. E. N_2 fixation associated with wood decayed by some common fungi in western Montana. Canadian Journal of Forest Research. 8: 341-345; 1978.

Larsen, M. J.; Jurgensen, M. F.; Harvey, A. E. N_2 fixation in brown-rotted soil wood in an Intermountain cedar-hemlock ecosystem. Forest Science. 28: 292-296; 1982.

Lull, H. W. Soil compaction on forest and rangelands. Miscellaneous Publication 768. Washington, DC: U.S. Department of Agriculture; 1959. 33 p.

Meier, C. E.; Grier, C. C.; Cole, D. W. Below and aboveground N and P use by *Abies amabalis* stands. Ecology. 66: 1928-1942; 1985.

Minore, D. Germination and early growth of coastal tree species on organic seedbeds. Research Paper PNW-135. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1972. 18 p.

Morrison, T. M. Absorption of phosphorus from soils by mycorrhizal plants. New Phytologist. 61: 10-20; 1962.

Mroz, G. D.; Jurgensen, M. F.; Harvey, A. E.; Larsen, M. J. Effects of fire on nitrogen in forest floor horizons. Soil Science Society of America Journal. 44: 395-400; 1980.

Nelson, E. E.; Harvey, G. M. Residues and forest disease. In: Environmental effects of forest residues management in the Pacific Northwest—a state-of-knowledge compendium. General Technical Report PNW-24. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974: S1-S9.

Niehoff, G. J. Effects of clearcutting and varying severity of prescribed burning on levels of OM and the mineralization of ammonium nitrogen in the surface layer of forest soils. Moscow, ID: University of Idaho; 1985. 43 p. M.S. thesis.

Nielson-Gerhardt, M. Effects of logging and mechanical site preparation on levels of mineralizable nitrogen and organic matter in forest soils. Moscow, ID: University of Idaho; 1986. 45 p. M.S. thesis.

Olson, J. S. Energy storage and the balance of producers and decomposers in ecological systems. Ecology. 44: 321-322; 1963.

Place, I. C. M. Comparative moisture regimes of humus and rotten wood. Silviculture Leaflet 37. Ottawa, ON: Canadian Department of Research and Development, Forestry Branch; 1950. 2 p.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Pregitzer, Kurt S. Relating predicted fertilizer response to actual growth and site conditions. 1984 December. Final Report, Agreement 22-C-3-INT-39. On file at: RWU 4152 files, Forestry Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Moscow, ID.

Ream, C. H.; Gruell, G. E. Influences of harvesting and residue management on small mammals. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 455-468.

Robinson, R. K. Ecology of fungi. London: English University Press Ltd; 1967. 116 p.

Ryan, K. C.; Noste, N. V. Evaluating prescribed fires. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W., tech. coords. Symposium and workshop on wilderness fire: proceedings; 1985 November 15-18; Missoula, MT. General Technical Report INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985: 230-259.

St. John, T. V.; Coleman, D. C. The role of mycorrhizae in plant ecology. Canadian Journal of Botany. 61: 1005-1014; 1983.

Stark, N. M. Impacts of utilization of nutrient cycling. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings; 1979 September 11-13; Missoula, MT. General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 123-136.

Swank, W. T.; Waide, J. B. Interpretation of nutrient cycling research in a management context: evaluating potential effects of alternative management strategies on site productivity. In: Waring, R. H., ed. Forests: fresh perspectives from ecosystem analysis. Corvallis, OR: Oregon State University Press; 1980: 137-158.

Trappe, J. M.; Strand, R. F. Mycorrhizal deficiency in a Douglas-fir region nursery. Forest Science. 15: 381-389; 1969.

U.S. Department of Agriculture, Forest Service. Environmental consequences of timber harvesting in Rocky Mountain coniferous forests: symposium proceedings.

General Technical Report INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 526 p.

Van Rees, K. C. J.; Comerford, N. B. Vertical root distribution and strontium uptake of a slash pine stand on a Florida Spodosol. Soil Science Society of America Journal. 50: 1042-1046; 1986.

Vitousek, P. M.; Gosz, J. R.; Grier, C. C.; Melillo, J. M.; Reiners, W. A. A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. Ecological Monographs. 32: 155-177; 1982.

Vogt, K. A.; Edmonds, R. L.; Grier, C. C.; Piper, S. R. Seasonal changes in mycorrhizal and fibrous-textured root biomass in 23- and 180-year-old Pacific silver fir stands in western Washington. Canadian Journal of Forest Research. 10: 523-529; 1980.

Weber, M. G.; Methoen, J. F.; Van Wagner, C. E. The effect of forest floor manipulation on nitrogen status and tree growth in an eastern Ontario jack pine ecosystem. Canadian Journal of Forest Research. 15: 313-318; 1984.

Wellner, C. A. Fire history in the Northern Rocky Mountains. In: The role of fire in the Intermountain West: symposium proceedings; 1970 October 23-29; Missoula, MT. Missoula, MT: Intermountain Fire Research Council; 1970: 42-69.

Yavitt, J. B. Nitrogen in lodgepole pine forests in relation to decomposition and soil solution chemistry. Laramie, WY: University of Wyoming, Department of Botany; 1984. 228 p. Ph.D. thesis.

Harvey, Alan E.; Jurgensen, Martin F.; Larsen, Michael J.; Graham, Russell T. 1987. Decaying organic materials and soil quality in the Inland Northwest: a management opportunity. Gen. Tech. Rep. INT-225. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p.

Organic debris, including wood residue, is important to the development and function of forest soil. Organic matter stores nutrients and moisture plus it provides important habitats for microbes beneficial to tree growth. To protect long-term forest soil productivity, organic horizons and their parent materials should be maintained.

KEYWORDS: forest soil, organic reserves, soil microbes, nitrogen fixation, ectomycorrhizae, harvesting and fire effects, regeneration, site preparation, soil management

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

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